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Pollen phenology distributions and modeled concentrations in Thessaloniki, Greece

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This study aims on the analysis of the pollens' phenological distributions in the greater area of Thessaloniki, over the years 2016-2020. The pollen index of the most contributable taxa of pollen spectrum is presented and is compared with similar studies. The effect of the common Gaussian distribution on the diagnosis of the pollen concentrations is tested for Quercus taxa with the WRF-NEMO-CAMx modeling system. The modeling system consists of three models in series, the Weather Research and Forecasting (WRF) meteorological model, the Natural Emissions Model NEMO and the chemistry – transport model CAMx. The overall performance of the modelling system shows that oak pollen concentrations do not diverge significantly from those observed. In addition, regularity tests revealed a decreasing trend in timeseries, while exponential distribution proved to describe pollen concentrations with a small deviation in contrast with the Gaussian, which was used of its simplicity in pollen data analysis.

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PoS(BPU11)199

1. Introduction

Epidemiological studies indicate that pollen is one of the main environmental factors, which affects up to 40% of the global population [1], [2]. In urban European cities, pollen from wind-pollinated plants triggers a variety of clinical diseases [3], and especially allergy-related respiratory diseases are considered as one of the most important public health problems for the 21st century [4], [5], [6]. The allergic reactions on adults and children will increase by 2025 [5], while on average the concentration of atmospheric pollen doubles every decade [7]. Due to direct influence on quality of life [8], the prediction of pollen concentration is principal in westernized societies.

Current pollen forecast can be based on either statistical and/or numerical models, which are using climatological values or phenological observations [9]. The statistical models utilize pollen concentrations from the monitoring stations, meteorological data [10], [11] or climatic factors (rainfall in the previous autumn, temperature in previous winter or autumn) and in some cases regression methods (Bagging for Regression Trees, Stepwise Regression, Partial Least Squares) and statistical tools (Principal Component Analysis) [12] for processing data. Numerical models include the synergy of forecasted meteorological fields to drive pollen emissions [13], [14], [15], [16].

In Greece, there is not a modeling system for forecasting pollen concentration for specific taxa. The existing studies in Thessaloniki and Athens are based on observational data [7], [17], [18], [19] and in field measurements [20], [21], [22] in order to estimate the pollen spectrum of the cities.

Furthermore, the development of the modeling system requires the usage of the proper distribution model that fits effectively the pollen data series. For the city of Thessaloniki, there is currently no corresponding study. In Catalonia, Spain, [23] and Poland [24], [25], attempts were made for performing gamma, gaussian and logistic distribution models concerning pollen daily concentrations.

The aim of this study is the analysis of the pollens' phenological distributions and the applicability of a high resolution modeling system in order to predict accurately surface pollen concentrations in the greater area of Thessaloniki, Greece. The Quercus taxa is selected for this purpose as one of the most contributable taxa and for the year 2016 has its highest peak. The modeling system consists of three models in series: a) the meteorological model WRF [26], b) the Natural Emissions MOdel (NEMO) for the production of the Quercus pollen emissions [27], [28], [29] and c) the chemistry-transport model CAMx for the advection and the deposition [30]. The next section describes the modeling system, the measurements and the statistical metrics. Section 3 presents the evaluation of the modeling systems' output for the Quercus pollen concentrations of the selected period. In Section 4 the pollens' phenological distributions are discussed, while Section 5 summarizes the main results and provides directions for future work.

2. Materials and Methods

2.1 Overview of the Modeling System

In studies [31], [32], the modeling system consists of i) the meteorological model, ii) the natural emissions model and iii) the transport model. The WRF (Weather Research and Forecast) v4.1 [26] selected as the most popular meteorological model in order to perform 4-day intervals simulations and producing hourly meteorological fields [27], [28]. WRF meteorological fields, producing biogenic, sea salt and desert dust emissions drive the Natural Emissions' MOdel (NEMO) on an hourly basis [33]. NEMO is modified to include Quercus pollen emissions. Firstly, conversions concern the yearly available pollen grains/m^2 (PEP). European Forest Inventory [34] at a spatial resolution of 1km provides Quercus area fractions. The area fractions are then multiplied by 457 10^7 pollen grains/crown m^2, deriving the final yearly available pollen grains. Secondly, physical mechanisms are necessary for describing pollen emissions. Inhibition factors of precipitation, wind and relative humidity [35] are adopted based on the applicability of Helbig's algorithms [14]. Gaussian distribution aids to calculate the fraction of PEP for each day for Quercus taxa phenology [16]. From available observations in Thessaloniki, the main pollen season is derived using the 95% method [36], which corresponds to 23th of March, the maximum to 17th of April and the ending date to 15th of May for the year 2016. Year 2016 has been designated as reference for Quercus because the highest peak showed. Consequently, period 23 March–15 May was selected to perform the simulations by the modeling system.

The scheme of pollen emissions adopted in NEMO takes the following form:

$$E_{pollen}(x, y, t) = c_b f_w f_r f_h \gamma \frac{PEP}{\Delta z} u^* \quad (1)$$

where γ is the daily fraction of PEP, u* is the friction velocity, f_w, f_r and f_h are the inhibition factors for wind, rain and humidity, respectively, Δz is the first layer of the modeling system, equal to 28m in this study, and c_b is a constant equal to 10^{-4} [14]. The chemistry-transport model CAMx [30] at INERT mode (no chemistry) is utilized for the advection and deposition of pollen grains in order to estimate the hourly surface pollen concentration in the greater area of Thessaloniki.

The modeling system is applied in a nested grid (*Figure 1*). The domain d01 covers the south and central part of Europe at 18km horizontal resolution, d02 covers the southeastern Mediterranean, centralized over Greece at 6km, and d03 covers the greater area of Thessaloniki at 2km spatial resolution.

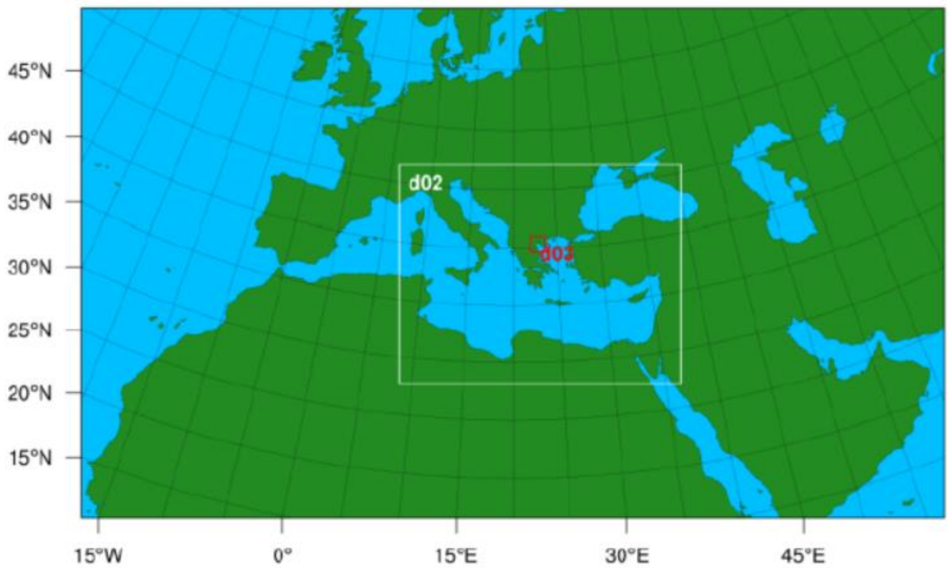

Figure 1: Modeling System nested grid

2.2 Measurements and Evaluation

The meteorological model's performance was evaluated using available ground based daily meteorological measurements and concentration levels provided by the National Network of the Climate Change and its Impacts project (CLIMPACT) [37] for three representative stations. The variables of surface air temperature, wind speed and relative humidity are utilized for this purpose. Model's validity and reliability are described in the studies [31], [32].

The evaluation of the CAMx output was achieved by using the daily airborne Quercus pollen concentrations. A 7-day Hirst-type volumetric sampler [20], [22], [38] is located at the roof of the Department of Biology at the campus of Aristotle University of Thessaloniki, in the city center (40º 38' 00" N, 22º 57' 26" E), at 30m a.g.l. The station is operating continuously since 1987 [7], [18], [39] and the standard guidelines of the European Aerobiology Society [40] were applied for pollen counting.

For the evaluation of CAMx pollen concentrations model, the standard statistical metrics that are used are the Mean Bias (MB), the Mean Absolute Error (MAE), the Index of Agreement (IOA), which reflects the overall performance, the Normalized Mean Absolute Error (NMAE), the Fractional Bias (Fb) and the Fractional standard deviation (Fs), in order to compare the relative errors with the 50% acceptance level [41].

3. Results

Table 1 presents the Pollen Index (PI) for the years 2016-2021. Year 2018 is absent due to data lacking. PI is derived by summing all the daily counts of a particular year or of studied years. Cupressaceae and the family of Gramineae, which includes the species of Urticaceae and Poaceae, have the highest contribution in the city of Thessaloniki. Then follow the deciduous broad-leaved forest trees, Quercus, Platanus and Carpinus, and the taxa of Pinaceae and Oleaceae. The year 2017 has the highest sum value, while year 2019 the lowest. The results are in agreement with corresponding studies in Thessaloniki area [7], [18], [19], [22], [42].

a/a	Taxa	2016-2021	2016	2017	2019	2020	2021
1	Cupressaceae	42525	8004	12133	7747	7016	7622
2	Urticaceae	24240	4940	5962	4161	4804	4371
3	Quercus	19455	4675	4117	2683	2023	5956
4	Platanus	12901	2870	1495	2316	2446	3769
5	Pinaceae	8640	2608	1631	1301	1116	1982
6	Carpinus	3295	1230	214	66	1630	154
7	Oleaceae	1769	352	249	499	383	284
8	Poaceae	1400	416	168	200	261	353
Sum		117140	25905	26401	19576	20350	24906

Table 1: Pollen Index of study years 2016-2021

Quercus pollen taxa has been reported as the third important component of pollen spectrum in Thessaloniki. After utilizing the 95% method [36] for the whole study period, the main pollen season (MPS) of year 2016 presents the largest duration (56 days) and the earliest starting (24 March). The year 2021 has the latest starting (26 April) and the MPS lasts only 32 days. The earliest ending is in year 2017 (13 May) and latest in year 2019 (30 May). Generally, MPS shows a systematicity in its beginning, end and duration over the course of five years. In correspondence to available observations year 2016 has its highest peak at 670 grains/m^3 (14 April), as shown in *Figure 2*, and it is been selected as reference year for performing the modeling system's simulations.

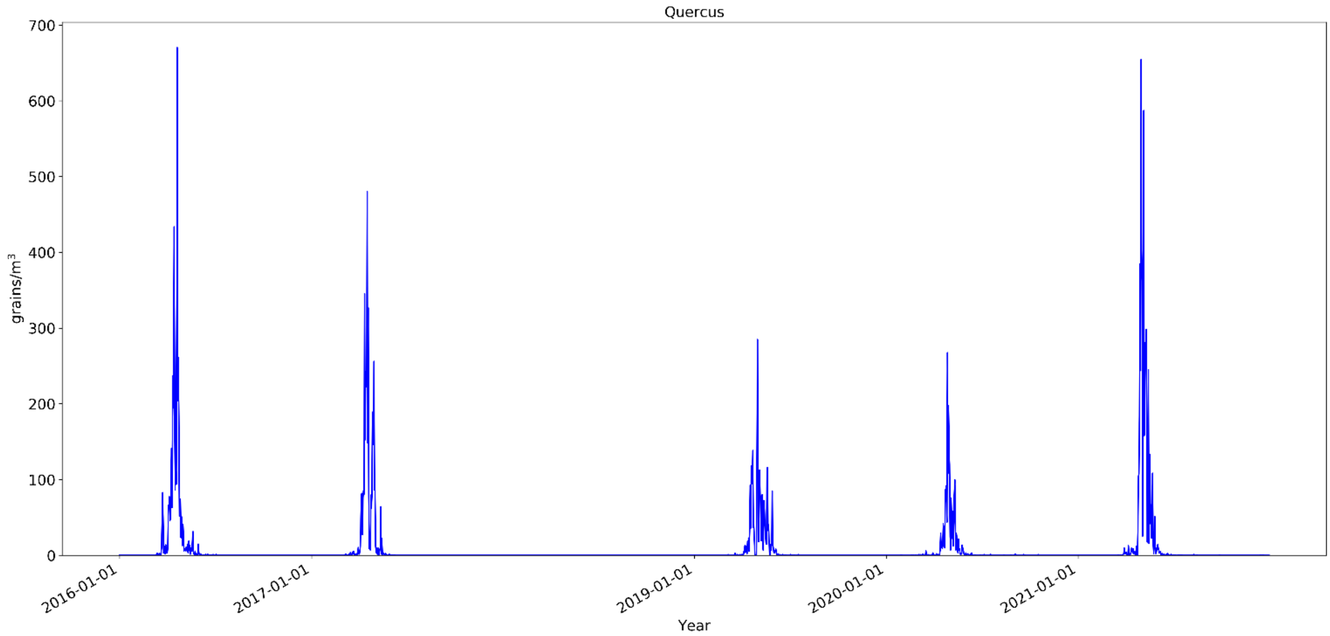

Figure 2: Quercus pollen concentrations 2016-2021 in Thessaloniki, Greece

In addition, the Mann-Kendall test was used to detect trend in Quercus taxa concentrations. Is a non-parametric statistical test to detect the presence of a monotonic increasing or decreasing trend within a time series in absence of any seasonal variation or other cycles, while its use in pollen data is widespread [43], [44], [45], [46], [47]. Test showed a decreasing trend, which is depicted by the negative z-value index -2.35 and p-value being lower than 0.05 (~0.018).

Figure 3 presents the timeseries of the observed and simulated daily Quercus pollen concentrations from the greater Thessaloniki area (domain d03) for the period 23rd of March to 15th of May. The patterns follow one another and the model satisfactorily predicts the daily variability and the two peak concentrations on 14th and 20th of April. The modeling system in general underestimates the observed concentrations at the beginning and the end of the MPS, due to uncertainties in wind speed meteorological calculation. From the aspect of statistical metrics (*Table 2*), the underestimation of the modeling system is evident by MB ~43 grains/m^3 and MAE ~50 grains/m^3. The good overall performance is apparent through the IOA index (0.86), while Fs value demonstrates that the error originates from bias and attains the 50% acceptance criterion. On the other hand, NMAE (0.59) and Fb (-0.69) slightly exceed this criterion.

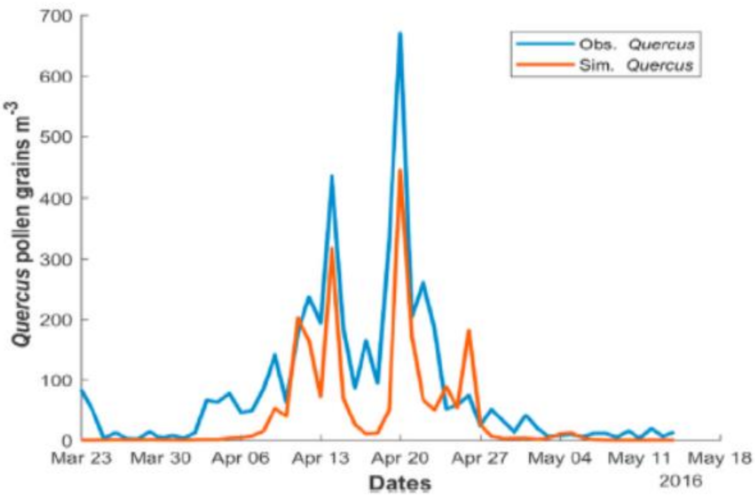

Figure 3: Timeseries of the observed and simulated Quercus pollen concentrations for the period 23 March - 15 May of 2016.

MB	MAE	NMAE	Fb	Fs	IOA
-43.37	49.99	0.59	-0.69	-0.37	0.86

Table 2: Statistical metrics for the evaluation of the modeling system simulations

4. Discussion

For the modeling system's simulations, the common Gaussian approach was used to calculate the Quercus taxa phenology [16]. The normal distribution of the data was tested using the Kolmogorov-Smirnov, Shapiro-Wilk and Lilliefors tests. These tests showed that daily data did not follow a normal distribution and they are being extremely right-skewed. These results in pollen data series have been replicated in similar studies [48], [49], [50], [51].

As null hypothesis is rejected, the Fitter Python Library [52] is used to identify the best distribution from which a data sample is generated. It uses 80 distributions and allows checking the best parameters of the most probable distributions. The parameters are Sum of Squares Error (SEE), Akaike Information Criterion (AIC) and Bayesian Information Criterion (BIC). SSE is the difference between the predicted value and the sample mean, AIC is an estimator of prediction error and thereby relative quality of statistical models for a given set of data and BIC is a criterion for model selection among a finite set of models. The model with the lowest AIC and BIC offers the best fit and generally is preferred.

Figure 4 displays the distributions plot for the Quercus observational data for the studied period 2016-2021. The distribution that best fits data is Half-Cauchy exponential distribution and then are presented in order the Gibrat's, Gamma, Skew normal and normal Gaussian distribution. Exponential distribution proved to describe pollen concentrations with a small deviation in contrast with the Gaussian. The statistical parameters depict similar results, as seen in *Table 3*. The exponential distribution Half-Cauchy approaches more the value 0 in the error SSE, at the same time it also presents the smallest values of the criteria AIC (2000.55) and BIC (-665511). In contrast, the normal distribution has the highest values out of the five.

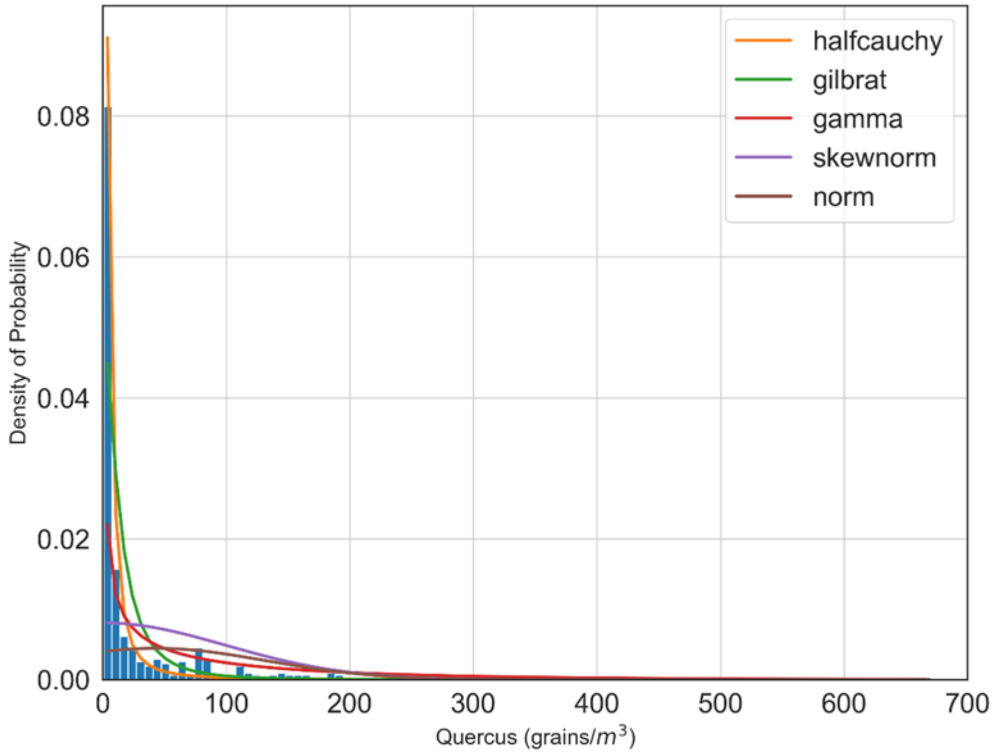

Figure 4: Best Distributions plot of Quercus taxa phenology

Distribution	SSE	AIC	BIC
halfcauchy	0.00021	2000.55	-6655.11
gilbrat	0.00180	2220.27	-5675.07
gamma	0.00363	1544.45	-5348.16
skewnorm	0.00575	2499.87	-5137.53
norm	0.00622	2625.21	-5108.10

Table 3: Statistical parameters of the most probable distributions

Modifications to the development of the modeling system should be studied in the future. Next step should be to use the exponential distribution instead of the normal one to study the phenology of each species. The application of the modeling system for the area of Thessaloniki for several pollen taxa will provide information on the variability of its concentrations throughout the year and will include species with high allerginicity to the general population, such as Cupressaceae, Oleaceae and Urticaceae taxa. Subsequently, this process should be extended to other regions of Greece and the southeastern Mediterranean, in order to evaluate the model with a more holistic and robust approach.

5. Conclusion

In this study, analysis of the pollen spectrum is conducted in the city of Thessaloniki, while a modeling system has been implemented for the Quercus taxa in order to accurately predict the surface pollen concentrations. The modeling system was evaluated for the phenological period of the year 2016. The model showed that could satisfactorily predict the phenological timing and the

PoS(BPU11)199

daily variability of the pollen concentrations. In addition, it captures the two peak concentrations on April 13th and April 20th. Nevertheless, the model underestimates the observed concentrations, especially during the start and end of the pollen season. The distributions plot for the Quercus observational data were studied. The data show right skewness and Half-Cauchy exponential distribution best fits them due to describing pollen concentrations with a small deviation in contrast with the Gaussian.

Additional aspects of the modeling system should be investigated in the future. The next step should be the application of the exponential distribution instead of the Gaussian at the modeling system for the study of variations in pollen concentrations. This process should be extended to more pollen taxa, like Cupressus and Olea, in the greater area of Thessaloniki for multiple years, taking also into account the interseasonal variability. Furthermore, the applicability of the model to Athens, other areas in Greece and in the Mediterranean region will contribute to the verification of estimated concentrations and the comparison of pollen levels in areas of similar and/or different climates.

Data Availability Statement: The pollen observations of the Department of Biology of the Aristotle University of Thessaloniki are provided from the Municipality of Thessaloniki (MoT) at https://envdimosthes.gr/fisika-aerioallergiogona/, accessed on 11 August 2022.

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PoS(BPU11)199